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Agricultural Research

Bringing Forth the Best

Mapping the Plant Genome

As much as we've heard about the advent of biotechnology in the plant sciences, when will we actually realize its improvements in our crops?

According to Jerome Miksche, director of USDA's Plant Genome Research Program, we can expect results from biotechnology in proportion to the effort that we put into it.

While the Green Revolution, a triumph of traditional plant breeding, captured the public's imagination, these achievements were more than 20 years in the making. Traditional plant breeding has been and still is a workable process for meeting the food and fiber needs of humankind. Yet to ensure—predictably—the expression of desirable plant traits, a more thorough understanding of gene systems and their associated biochemical regulatory pathways is needed.

Although advances are still being made under conventional plant breeding technologies, the curve appears to be flattening on the improvement rate for yield and other factors in several important commodities.

It is time for biotechnology to quicken the pace again—to identify a desired plant trait, be it drought resistance or improved nutrient production, and then locate the specific gene systems that cause that trait to be expressed. And once these are mapped, genes can in some cases be moved from organism to organism via transfer shuttles. Results that once required years of plant breeding can be achieved rapidly and with increased precision.

Needless to say, plant breeders, molecular biologists, and physiologists are champing at the bit. After all, global acclaim awaits the research team that develops a wheat that's invulnerable to all rusts or a corn that can fend off the notorious rootworm. From their point of view, the nation's commitment to biotechnology ought to logically follow from the nation's concerns about solving fundamental agricultural problems. Billions of people stand to have their lives improved by an increase in the world's food supply.

In an effort to promote understanding of the organization and function of plant DNA, so crucial for the effective use of genetic resources, USDA has established the Plant Genome Research Program, with the Agricultural Research Service in a coordinating role.

The program is focusing on such objectives as:

- Advancement of genome technology itself.
- Construction of low-resolution maps for major crop species important to the United States about which little information is now available.
- Construction of high-resolution genetic maps of plant species with sufficient background information already available, such as tomatoes, corn, and rice.
- Comprehensive analysis of the gene sequences in the laboratory plant *Arabidopsis*. Research on this tiny, but very useful plant model will be conducted in cooperation with the National Science Foundation, the Department of Energy, and the National Institutes of Health.

So, to concerns that biotechnology must fulfill its promise, the answer lies not only in broadening our insights into the tiny, secret world of the gene, but also in keeping our eye on the many pressing real-world agricultural applications that await biotechnology. In a briefing to the USDA National Plant Genetic Resources Board, program director Miksche threw down the gauntlet:

"The Nation is faced with major agricultural challenges of safeguarding water quality, adapting to climate changes, using sustainable agriculture, developing new crops, finding new uses for crop and forest products, improving food quality and safety, continuing germplasm exploration and enhancement, and expanding biocontrol measures. To meet these challenges and find answers to the complex issues involved, research is needed to locate related plant genes."—**Regina Wiggen**

Agricultural Research

Cover: Dozens of improved varieties of fruits, nuts, and vegetables continue to emerge from laboratories and greenhouses of USDA's Agricultural Research Service. Next to the box of oversized thornless blackberries are star-shaped slices of carambola, a tropical fruit now grown in Florida; adjoining the pecans are dark red lychee nuts, long familiar to Chinese cooks. The wide-mouthed jars each contain 75 tiny strawberry plants, grown through tissue culture.
Photo by Tim McCabe. (K-2282-1)

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BOB BJORK

ARS plant geneticist Keith Schertz examines grain sorghum bred for tropical climates. Bags prevent sorghum flowers from cross-pollinating, making it easier to breed for desired traits. (K-2492-13)

In Search of Perfect Plants

ARS plant breeding research today

Humans have been breeding plants by observation and selection for thousands of years and more scientifically for about 100. Aiding and abetting evolution in this way, we have dramatically increased yields, geographic range, disease and pest resistance, tolerance to environmental stress, and quality of nutrients and fibers.

Having come so far, why continue? Aren't returns diminishing?

"Not really," says Henry L. Shands, ARS national program leader for germplasm research. "American farmers grow more than 200 varieties of wheat, 85 varieties of cotton, 200 varieties of soybeans, and many varieties of fruit, vegetable, and ornamental crops. Disease and pest resistance must be bred into each of these varieties, which often thrive only in specific, limited growing areas."

One crucial reason for ARS to maintain an active plant breeding program is to keep step with continually evolving plant enemies.

"Pests such as insects and pathogens have an amazing capacity to break crop resistance," says Shands. Resistant varieties usually become obsolete in 3 to 10 years. And it generally takes 8 to 11 years to breed new ones in ongoing programs."

In keeping up with known pathogens and pests, plant breeders at least have a head start—they know something about the enemy and something about the way the plant has been bred to resist earlier versions. Newly introduced diseases and pests such as the Russian wheat aphid often present a more difficult problem.

The Russian wheat aphid first appeared in the United States in 1986 and has since cost wheat growers over $200 million. Since this was a newly introduced pest, wheats currently being grown had little resistance. Control so far has been largely chemical, a costly measure. The mix of alternatives includes finding biocontrol agents and developing resistant varieties.

"Resistance found in wheat varieties imported from Southwest Asia is now being bred into commercial varieties," says Robert L. Burton, an ARS entomologist at the Plant Science Research Laboratory in Stillwater, Oklahoma. "While we've found common wheats that tolerate the aphid feeding, their wild relatives and ancestors may provide new genes with additional aphid resistance." He estimates that it will take 5 to 10 years to breed in strong aphid resistance.

Fortunately, newly introduced pests as devastating as the Russian wheat aphid aren't common. Most ARS plant breeding is aimed at solving, or at least staying ahead of, such chronic problems as the Hessian fly, another wheat pest.

The National Plant Germplasm System

Whether the better plant is meant to overcome a chronic problem or an immediate threat, breeding it would take even longer if we didn't have an established system of plant germplasm collection and preservation—the National Plant Germplasm System, which is managed by ARS in close cooperation with the states.

The NPGS collects, evaluates, catalogs, preserves, and distributes plant germplasm from all over the world. Germplasm collections are essential to the plant breeder, for they provide the raw genetic material from which new varieties are bred.

Ability to develop new varieties depends on genetic diversity, and wild ancestors and relatives of cultivated plants are the keys to that diversity. But the amount of land where plants grow wild continues to diminish, and many plant species and varieties are disappearing forever.

"Without NPGS," Shands points out, "many wild relatives and ancestors of economically important crops would be lost and the gene pool for plants would shrink dangerously." To help prevent this loss, NPGS contains about 400,000 plant introductions—germplasm of domestic and foreign plants, wild and weedy relatives of crop species, varieties created through planned breeding programs, elite breeding lines, some rare and endangered species, and genetic stocks.

Genetic stocks include induced and natural mutations, cytological (cellular) stocks of genetic oddities and variations on normal chromosomes, marker genes, polyploids, and pest-resistant stocks.

Plant explorations add new germplasm to the system. Explorers search for the wild relatives and ancestors and for new species and varieties with crop potential. Most NPGS-sponsored plant exploration takes place outside the United States because few commonly cultivated crop species are native to North America north of Mexico.

Recent expeditions sponsored by NPGS have gone to high South American plateaus for potato relatives, to North Africa for wild wheat, and to southwest Asia for alfalfa. One expedition searched Minnesota for cranberries. Cranberries, strawberries, blueberries, raspberries, blackberries, sunflowers, and several tree species are among our few economically important native crops.

At the National Seed Storage Laboratory in Fort Collins, Colorado, seeds are packaged in flexible moisture-proof bags. (K-1657-16)

JACK DYKINGA

Overseeing plant exploration and exchange for NPGS is the ARS National Germplasm Resources Laboratory at Beltsville, Maryland. This lab also catalogs accessions, assigns them plant introduction numbers, and distributes germplasm to the various collections in the system. It administers the ARS part of the National Plant Germplasm Quarantine Laboratory *[Agricultural Research, September 1990, p. 22]*. It also maintains the GRIN (Germplasm Resources Information Network) computer database and assists the crop advisory committees.

GRIN stores detailed information about each plant introduction in NPGS. Using GRIN, breeders can search for germplasm having particular characteristics they may want to try to add to a plant.

Crop advisory committees counsel NPGS on most of the economically important food, fiber, industrial, and ornamental crops. Committee members are world authorities on the particular crop—breeders, pathologists, geneticists, and entomologists drawn from federal agencies, state universities, and commercial companies.

Desirable Characteristics

In addition to providing advice, the specialists who make up each crop advisory committee help set priorities about acquisitions, maintenance, evaluation, and enhancements needed for the crop.

Until recently, the most desirable characteristic for crop plants has been higher yield. Today's plant scientists, says Shands, also look for greater efficiency, ways to grow crops on increasingly marginal land, and ways to reduce inputs—chiefly fertilizers, pesticides, and water—that are costly, both economically and environmentally.

Navel oranges

Corn rootworm beetle

Cotton

Major needs are usually disease and pest resistance, but other characteristics are desirable too. "There are," he says, "about 50 controllable factors in plants." These include yield; cold hardiness; heat and drought tolerance; shape and color; sugar, starch, protein, fiber, and oil content; height; salt tolerance; palatability, flavor, and texture; and time to maturity.

Desirable characteristics ARS scientists are breeding into a representative sampling of major crops—

Citrus—Cold hardiness. Citrus trees that can withstand cold winter freezes, which come erratically to Florida and Texas groves, could help stabilize supplies and increase America's share in national and international markets. ARS citrus breeders are also looking for trees more tolerant of salty and marginal soils found in California.

Corn—Resistance to corn borers and rootworms. Resistance to the corn rootworm alone could bring substantial savings: It costs a billion dollars a year in losses and control measures. Corn breeders are also developing plants resistant to fungal and bacterial diseases.

Cotton—Insect resistance. ARS scientists in Arizona have developed cotton plants that suffer only half the damage once inflicted by pink bollworm. This should help cut down on the amount of pesticide needed to control cotton insects—currently as many as 15 applications in one growing season. Another cotton-breeding goal is better fiber quality.

Grasses—Better nutrition and greater durability. Fortunately, most grasses aren't plagued by insect or disease infestations that can ruin field crops. That leaves researchers free to work on grasses that provide greater nutrition for grazing livestock and wildlife, withstand animal trampling, and hold up under environmental stresses—heat, drought, wind, cold, and salty soils.

Rice—Increased market share. ARS researchers are looking for new traits that would make rice more profitable, including unique long-grain rices to compete in international markets. Disease and insect resistance are also high on the list of priorities.

Soybeans—High protein and high oil content in the same plant. Such a crop could be sold as either feed or food, depending on market conditions. So far, oil content has gone down in soybeans bred for higher protein. Other goals: Custom-building soybeans with improved, more nutritious oils and increasing yield for more efficient return on labor and production costs

The simplest way to improve a crop variety is to observe how this year's crop performs, select the plants that do best, and use their seed, seed pieces, or other vegetative parts to plant next year's crop. People have been doing this for thousands of years.

When a desirable characteristic is controlled by just a few genes and its expression is not influenced by the environment, it is called a qualitative character. The chief difference between field corn (starchy, used for livestock feed) and sweet corn (sugary, used for food) is a qualitative character.

Breeding for qualitative characters is usually simple and quick because they're fairly easy to isolate and evaluate. Unfortunately, many desirable characteristics—such as cold hardiness, drought tolerance, and yield—are quantitative instead. A quantitative character is controlled by many genes and can be heavily influenced (as much as 95 percent) by the environment.

So breeding for quantitative characters is much more painstaking. The scientists must record and process detailed statistical data to account for environmental influence on variation in plant performance.

Resistance to diseases, insects, and other pests might be controlled by 1 gene or by more than 100, depending on both plant and pest.

Also, changes in one characteristic can affect another, sometimes positively, sometimes not. ARS scientists trying to develop the high protein/high oil soybean are wrestling with this problem because so far raising the amount of protein has lowered the oil content.


Gamagrass


Rice


Soybeans

Sugarcane, a Case in Point

In plant breeding, then, complications abound. Sugarcane, for example, is still bred mostly through classical techniques. But: "Sugarcane is very complex genetically," says Jimmy D. Miller, ARS plant geneticist with the Sugarcane Production Research unit in Canal Point, Florida. "Commercial canes are hybrids of 3 or 4 different species each with 105 to 110 chromosomes."

Working with such a large number of chromosomes—in contrast, corn has 20—and with the complex relationships of the different species can be very involved. The number of possible combinations is correspondingly large.

"We start with 100,000 sugarcane seedlings each year and hope to find one that possesses the superior genetic material we're looking for," says Miller.

These seedlings are from intercrosses Miller and his colleagues have made among existing hybrids. Each year, about 10 percent of the seedlings are progenies of germplasm taken from the diverse NPGS sugarcane collection at Miami.

The 100,000 seedlings are planted at the Sugarcane Field Station. "At the end of the first year, we select about 10 percent of the 100,000 seedlings by visual inspection," Miller explains.

"At the end of the second year, we narrow that 10 percent down to 1,000. The 1,000 selected clones are planted and sampled at 1 location the next year. And 131 are selected for continued testing for 2 years at 4 locations by cooperating Florida farmers on various soils—Lauderhill muck, Terra Ceia muck, Torry muck, and Pompano fine sand.

Why 131? "Because that's how many we can load on our truck." Miller chuckles. "A few years ago, we were using 10-stalk samples of 100 clones. We didn't really need 10 stalks, so we cut back to 8. When I came out one day to check on the loading of the truck, I noticed that it was only two-thirds full. I asked why the loading wasn't finished, was told that it was, and realized we had room to add more selections. We'd like to be able to do even more."

Truck size isn't the only limiting factor, of course. "From the 131 clones, we select and test 8 to 11 outstanding clones for 3 more years at 9 locations. It's 8 to 11 because with 4 rows of 4 replications, that's about all that can be harvested in a day by 8 canecutters."

Clones that successfully complete these experimental phases undergo 2 to 4 years of evaluation and increase in stocks of seed cane by the Florida sugarcane industry before commercial release.

That's a 9-year process of testing and selection. In those 9 years, scientists gather meticulous data on yield, sugar content, and disease resistance.

Is all this time and expense justified? The U.S. cane sugar crop is worth about $800 million a year, and there are six cane diseases—including sugarcane rust—that could reduce yields enough to make production uneconomical.

A seventh disease—caused by a virus called sugarcane bacilliform—was unknown until about 3 years ago. It has been detected in 90 percent of the *Saccharum officinarum* clones tested from the collection in Miami. *S. officinarum* is the most important parent species of commercial sugarcane hybrids.

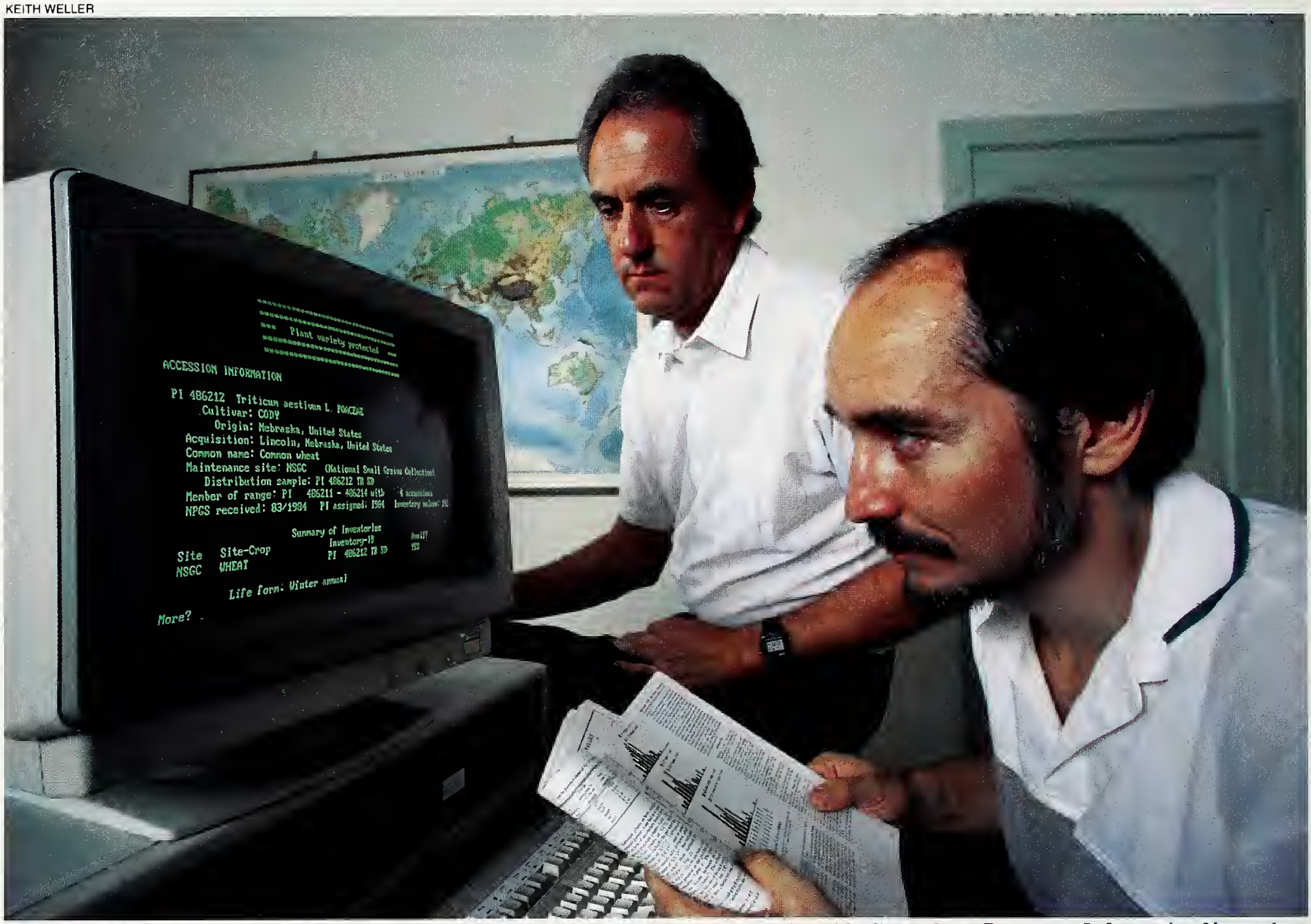
"But the disease is so new, we don't know how much damage it can cause," says Miller. Fortunately, most commercial varieties tested last winter didn't have the new virus.

Though the Canal Point scientists are keeping a watch on the new virus, breeding for resistance to sugarcane rust remains a high priority. Miller says chemical measures that prevent sugarcane rust are prohibitively expensive.

Hustling Nature

The 9 years it takes to breed and test sugarcane is only one example, about average for ongoing programs. Ordinarily, says Shands, "it can take 12 to 15 years to breed new varieties starting from introducing some raw germplasm. We can do crash programs in less time, but without some of the refinements. For instance, the first releases of wheat resistant to Russian wheat aphid may not be as uniform or have as strong a resistance as those 10 years from now."

KEITH WELLER



Database manager Jimmy Mowder (left) and botanist John Wiersema query the nationwide Germplasm Resources Information Network for information on wheat accessions. (K-3778-19)

If the problem is especially difficult, breeding and testing can take even longer. The cold-hardy Ambersweet orange took 26 *[Agricultural Research, July 1990, p. 13].*

Can the process be accelerated, made more efficient? "To some extent, yes," says Shands. "Computers have certainly helped us do onsite measurements and calculations. They speed up our decisionmaking." And using winter nurseries—such as those ARS maintains in Puerto Rico and Hawaii—can give breeders 2-1/2 or 3 generations in a year instead of 1.

Also, available technology now allows researchers to control climate and get more uniform screening for pest resistance. And wide-area testing—growing plants at many different locations at the same time—enables more comprehensive studies in a shorter period.

But genetic engineering is the chief means for increasing efficiency. In fact, Shands doubts that many of today's plant breeders are wholly traditional. "They're cross-trained," he says. "They either work with a molecular biologist or do the work themselves."

Genetic engineering techniques used in plant breeding include just about any method that goes beyond simply transferring pollen from one flower to another. Embryo rescue and tissue culture are two examples. The lethal gene technique in development at Albany, California, for producing hybrid tomato seed is another *[Agricultural Research, August 1990, p. 22]*.

Several ARS scientists have been developing pollen-storage techniques both for short- and long-term preservation and to overcome widely varying flowering times.

At the ARS National Seed Storage Laboratory in Fort Collins, Colorado, Kristina F. Connor, a postdoctoral research associate, is studying freezing of pollen in liquid nitrogen as a means of germplasm preservation.

Not all pollens freeze well, but Connor is working on that problem since pollen is easily shipped and wonderfully compact to store. She is currently comparing laboratory test results with field pollination for such plants as pears, citrus, and filberts.

(Continued page 10)

Giants Among Crop Breeders

Notable among ARS scientists are three whose contributions in breeding crop plants have had particularly wide-reaching effect—boosting the American economy and greatly helping to alleviate world hunger. Orville A. Vogel, Glenn W. Burton, and Edgar E. Hartwig are all members of the ARS Science Hall of Fame.

Orville A. Vogel was the first to breed a commercial semidwarf cultivar of a cereal grain in North America. He developed Gaines wheat, which established the high yield potential for soft white wheats worldwide. Wheats and cultivars developed from germplasm collected and assembled by Vogel contribute 20 to 30 percent more wheat to annual production in the three northwestern states.

He willingly shared his wheat germplasm with Norman E. Borlaug, leader of the International Maize and Wheat Improvement Center program in Mexico that launched the Green Revolution. When Borlaug received the Nobel Peace Prize for his work, he credited Vogel's contribution for the program's success. Now retired, Vogel was an agronomist at the ARS Wheat Breeding and Production unit in Pullman, Washington.

Glenn W. Burton developed Coastal bermudagrass and solved problems associated with its establishment and management. Coastal bermudagrass has been planted on more than 10 million acres in the southern United States.

The first commercial production of hybrid seed of pearl millet was a result of his four inbred line releases in 1962. Through his efforts, pearl millet became an important forage crop for the Southeast. In an extra boon for researchers, it also turned out to be an unusually effective laboratory plant for studies of breeding methodology, cytogenetics, and increased grain potential. Varieties and breeding techniques developed under Burton's guidance have had remarkable success in India, Mexico, Bolivia, and Brazil.

Burton, who has worked for USDA since 1936, is a plant geneticist at the ARS Forage and Turf Research unit in Tifton, Georgia.

Edgar E. Hartwig bred soybeans that helped transform them from an ordinary forage to the second most valuable U.S. crop and developed several cultivars that thrive in the South. From 1953 to the present, soybean acreage in the South increased from 2.5 million acres to 17.5 million, and average yields doubled to 24 bushels per acre; 90 percent of southern soybean acreage is planted with cultivars bred by Hartwig.

An agronomist with the ARS Soybean Production Research unit in Stoneville, Mississippi, Hartwig has been with USDA since 1949. He released his first important cultivar, Lee, in 1954; it became the South's leading soybean. Use of Forrest, a soybean Hartwig developed for resistance to soybean cyst nematode, reduced yield losses by an average of $80 million a year.

At Canal Point, Peter Y. Tai, an ARS plant geneticist, has developed a pollen-storage technique to use in breeding cold hardiness into commercial sugarcane. Previously, sugarcane pollen was thought to be usable for only 20 to 30 minutes. With his technique, Tai has been able to store pollen for at least 2 years yet still get viable progeny.

He dries the pollen out to about 5 to 10 percent moisture content, puts it in an ampule, and freezes it in liquid nitrogen. Using the pollen-storage technique, Tai is storing pollen from early-flowering sugarcane to be crossed with later flowering varieties. A major goal is to introduce the cold hardiness of early-flowering clones of *Saccharum spontaneum* into commercial sugarcane hybrids.

Tai's technique is based on a similar one developed by ARS plant geneticist Wayne W. Hanna in breeding research on pearl millets at the Forage and Turf Research unit in Tifton, Georgia.

Widely different flowering times is just one obstacle that genetic engineering helps to overcome. Another is sexual incompatibility: Because wild and cultivated potatoes can't be bred conventionally, for instance, ARS scientists have used a genetic engineering technique called protoplast fusion to produce hybrid potato plants with insect resistance built into their leaves [*Agricultural Research, February 1988, p. 15*].

Gene transfer techniques may one day be used to introduce desirable characteristics into a species from a wholly unrelated species.

But manipulation of DNA is relatively new and "still isn't up and running," says Shands. Not only are techniques continuing to evolve, but essential information about the genetic makeup of economically important crop species is only sporadically available. The Plant Genome Research Program is aimed at filling this knowledge gap. [See *Forum* in this issue.]

Genetic engineering in all its forms and computer modeling and data processing are relatively new tools for the plant breeder that have already helped make the research faster and more efficient.

But for as long as crops are planted in soil and grown in sunlight, they will still be subject to the laws of nature. Science may stretch the growing season, transform marginal land into fields and range, and outmaneuver the reproductive process. Yet plant breeders will still have to do what the farmers do—plant the crop, nurture it, and harvest it—and they may have to do so for several growing seasons to eliminate defects and problems.

However long it takes, producing a new variety isn't going to reward a plant breeder with instant gratification. Why do it then?

"It's creative," says Shands. "It's making something new and doing it a little bit better than anybody else has done it before. It's knowing that all those years of research will help to make new and better crops that are more profitable to the farmer and less costly and more healthful to consumers—to be able to feed more people while sustaining the productivity of the land."—By **Ruth Coy** and **Dennis Senft,** ARS.

TIM MC CABE

Tissue culture techniques allow tests to be run much more quickly and in less space than would be required if these peach trees were grown outdoors. (K-3111-5)

Henry L. Shands may be reached at Agricultural Research Service, USDA, Room 140, Bldg. 005, BARC-W, Beltsville, Maryland 20705 (301) 344-3311. ◆

Breeding Better Berries

A bright red strawberry that keeps its vivid color after freezing and thawing, a hardy, thornless blackberry, and a disease-resistant raspberry are the newest fruit offerings from an ARS horticulturist in Corvallis, Oregon.

Francis J. Lawrence bred the new berries using germplasm gathered 10 years ago, about a year before the USDA National Clonal Germplasm Repository in Corvallis—where he worked—was established.

"Today," says Lawrence, "it's easier to make crosses, now that plants and seeds are kept together in repositories that are easily accessible to researchers."

The Redcrest strawberry, targeted primarily for commercial growers, has slightly more acid (pH 3.1-3.2) than other popular varieties grown in the Northwest. That means it stays red even after thawing, a bonus for the frozen food market. The green cap pulls off the berry easily, making for quicker harvesting. Pickers for frozen food producers leave caps on the vines to save time, since the berries go straight to the processing plant.

The parent varieties, Linn and Totem, that were crossed to make Redcrest, are just two of the approximately 900 different strawberry accessions (plants or seeds) now housed at the Corvallis repository. In the genus *Rubus,* which includes raspberries and blackberries, the repository maintains over 1,000 different accessions.

The Waldo thornless blackberry bears glossy, black fruit with small seeds. The berries ripen slightly later than Marion, Oregon's best-selling variety, and are easy to pick. When a severe freeze last January killed buds on other varieties, Waldo held up well. The plants' secondary buds, which develop only in certain blackberry varieties and then only if the primary buds are damaged, went on to flower and produce fruit. Waldo is named for George Waldo, an internationally known former ARS scientist who developed the Marion blackberry and Willamette, the Pacific Northwest's leading red raspberry.

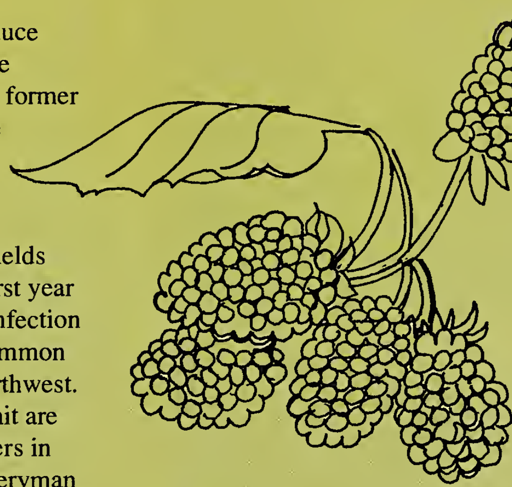
Summit, the new raspberry, yields bright red, rounded berries the first year after planting. The plants resist infection from root rot diseases that are common in the heavy, wet soils of the Northwest.

So far, both Waldo and Summit are selling well to commercial growers in the Northwest, according to nurseryman Charles C. Boyd of Cedar Valley Nursery in Centralia, Washington. Home growers will probably like Waldo too, he says, because "it's not as big and gangly as other varieties."

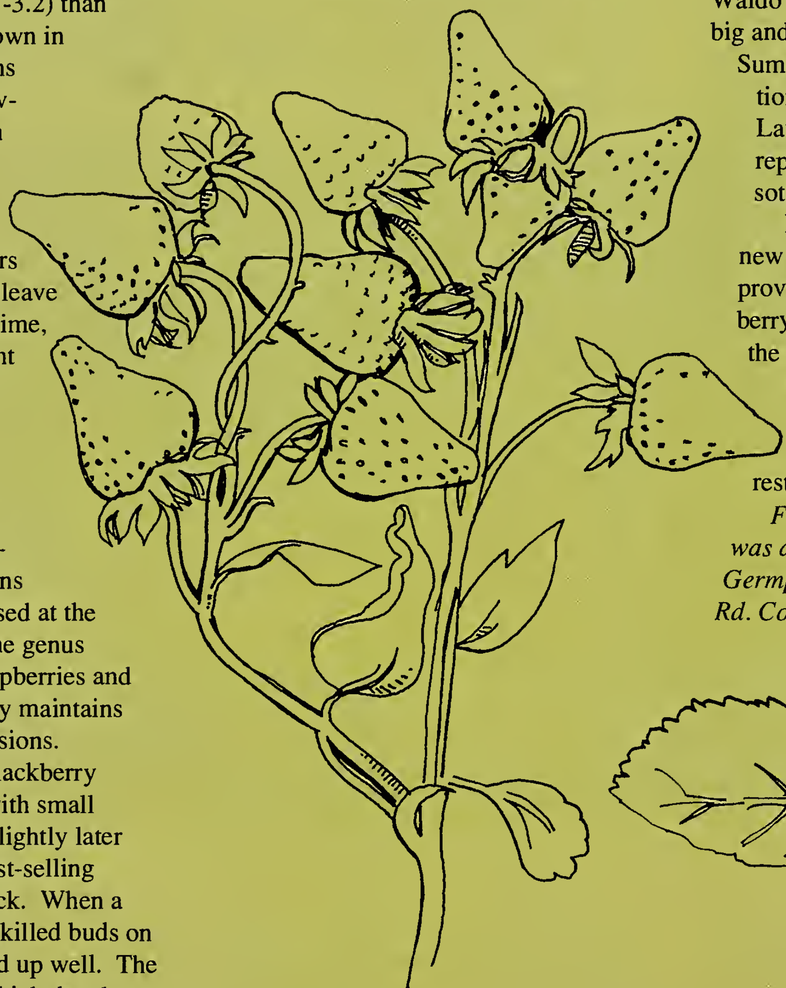
Summit will thrive in many locations around the United States; Lawrence received favorable reports from growers in Minnesota, Michigan, and New York.

Lawrence also worked on a new golden raspberry—an improved version of the amber berry that can better withstand the rigors of shipping. He hopes the berry will be released within 2 years as a novelty fruit for the fresh market and specialty restaurants.—By **Julie Corliss,** ARS.

Francis J. Lawrence (now retired) was at the USDA-ARS National Clonal Germplasm Repository, 33447 Peoria Rd. Corvallis, OR 97333 (503) 757-4448.



Waldo Blackberry



Redcrest Strawberry

Summit Raspberry

Breaking the Salmonella/Chicken Connection

Irradiation is approved for poultry processing

When the U.S. Food and Drug Administration approved irradiation of poultry in May 1990, that decision was based in part on research by Agricultural Research Service scientists.

In December 1986, the U.S. Department of Agriculture petitioned the FDA for approval of poultry irradiation, which is expected to benefit consumers by reducing spoilage and illness. The primary target was *Salmonella*—a bacterium that can contaminate chicken, turkey, and other fresh or frozen poultry and cause food illness or poisoning.

"Irradiation doesn't make poultry radioactive or unsafe," says Donald W. Thayer, a microbiologist in charge of ARS' Food Safety Research unit in Philadelphia, "but it does offer a means of substantially reducing the risk of foodborne pathogens.

Because salmonella bacteria are so widespread in the environment, fresh poultry can become contaminated even under the best of conditions.

The best way to prevent foodborne salmonellosis is through the use of proper food processing techniques, refrigeration, good household handling, and proper cooking.

A nationwide survey by USDA's Food Safety and Inspection Service found 35 percent of broiler chickens checked harbored the *Salmonella* microorganism.

On the average, Americans consumed 84.9 pounds of poultry in 1989, compared with 81.1 pounds in the previous year. Also, food companies are developing poultry products that can be cooked much faster in conventional and microwave ovens as well as precooked, ready-to-eat poultry products.

In response to such changes in the poultry industry, ARS scientists have added irradiation to proper cooking and refrigeration as effective tools for salmonella control.

Thayer says researchers at the Eastern Regional Research Center considered processing temperatures and packaging conditions as factors to help determine an effective irradiation dose to control or eliminate *Salmonella*. Researchers also studied how irradiation affects the vitamin content in poultry and conducted studies to see if any toxic products are formed by the treatment.

The maximum dosage approved by the FDA is 3.0 kiloGray and the minimum 1.5 kiloGray. A kiloGray is a unit of absorbed radiation energy.

"What we are saying is that the 3-kiloGray limitation approved by the FDA should provide ample protection for poultry," Thayer says.

Scientists found that 99.5 percent of *Salmonella* cells are inactivated at the minimum dose and 99.99 percent at the maximum level.

When raw poultry is irradiated to a dose as low as 0.9 kiloGray, the number of living *Salmonella* cells decreases by 31 percent, according to Thayer.

Irradiation followed by heating provides an extra punch.

"The important thing is that irradiation will provide a safer product, even if the treated product is held at proper storage temperatures before cooking," Thayer says. "There is a higher degree of safety because those cells that do survive irradiation treatment remain much more sensitive to heat, an effect that lasts up to 6 weeks.

To simulate the temperatures that poultry might encounter during processing, the samples were tested at temperatures from minus 4°F to 68°F above.

While the facts show that irradiation is an effective killer of harmful bacteria, the jury's still out on consumer acceptance. To answer some questions raised by consumers, Jay B. Fox, Jr., a research chemist at the Philadelphia lab, conducted an extensive study on vitamin changes in irradiated poultry.

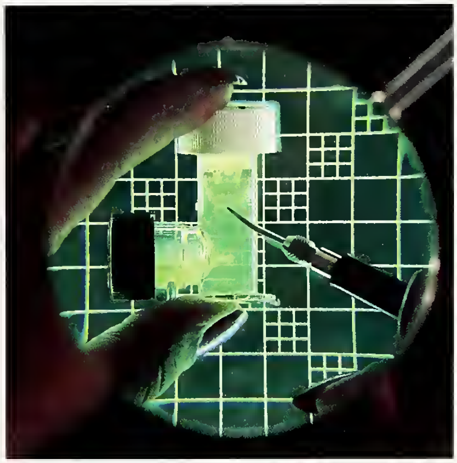
PERRY A. RECH

Chemist Bill Obermeyer places a plastic bag containing chicken into position for irradiation. (K-3783-20)

PERRY A. RECH

Microbiologist Donald Thayer replicates *Salmonella* colonies in various growth media. (K-3784-9)

PERRY A. RECH



PERRY A. RECH

(Top right) A new rapid detection test for *Salmonella*. The curved line at the tip of the pointer indicates the bacteria are present in this sample. (K-3783-10)

(Right) Each test card in microbiologist Glenn Boyd's hands takes the place of 30 test tubes during high-speed automated identification of bacterial isolates from poultry products. (K-3783-9)

Fox and other members of the research unit looked at how low-doses affect the B vitamins—thiamine, riboflavin, and niacin. Chicken breasts were cut apart, leaving the bones attached, and packed in vacuum-sealed bags before irradiation. After they received treatment at various doses, the samples were cooked in a conventional oven until they reached an internal temperature of 180°F. They were then analyzed for vitamin B content at the Philadelphia lab.

Fox found that irradiating the samples within the limits set by the FDA for chicken produced a thiamine loss ranging from 2.9 percent to 8.6 percent. However, the results indicated that there were no losses of riboflavin and niacin. The loss of thiamine from irradiated chicken was directly related to the temperature during irradiation, Fox says.

Chicken and turkey contribute about 0.9 percent of the thiamine, 2.16 percent of the riboflavin, and 8.22 percent of the niacin consumed in the American diet.

ARS also did nutritional, genetic, and toxicological studies of shelf-stable chicken sterilized by irradiation at doses 12 times greater than the maximum dose permitted for *Salmonella* control. No evidence of genetic toxicity or malformation in fetuses was found in mice, hamsters, and rats ingesting irradiated chicken as 35 percent of their total diet. Long-term feeding studies with mice and dogs did not produce evidence of either nutritional or toxicological effects on the animals.

USDA estimates that illnesses caused by *Salmonella* and other foodborne bacteria have a $1 billion to $10 billion economic impact through lost wages, decreased worker productivity, medical expenses, industry production losses, and destruction of products.—By **Bruce Kinzel**, ARS.

Donald W. Thayer and Jay B. Fox, Jr., are at the USDA-ARS Food Safety Research Unit, Eastern Regional Research Center, 600 E. Mermaid Lane, Philadelphia, PA 19118 (215) 233-6582. ◆

Preventing Diabetes With Chron

PERRY A. RECH

Chemist Richard Anderson examines data from a gamma radiation counter that indirectly measures blood insulin concentrations. (K-3722-2)

Some 6 million Americans are under treatment for type II diabetes—the kind that crops up during the middle years of life and accounts for 90 to 95 percent of diabetes cases. Another 5.3 million people are believed to have type II diabetes but don't know it, putting the total number of cases at "about 11 million plus," according to the National Diabetes Information Clearinghouse.

And for each person with full-fledged diabetes, there's another one in the wings, whose insulin is no longer as efficient at getting circulating glucose into body cells and converted to energy.

Aside from keeping body weight down and avoiding too much dietary sugar, is there anything else a person can do to prevent the disease?

ARS' Richard A. Anderson thinks so. Studies dating from 1966, including the most recent one conducted by his laboratory at the Beltsville Human Nutrition Research Center, show that adequate amounts of the essential element chromium can improve glucose tolerance in the majority of people with elevated blood sugar—as long as they still secrete insulin. During the 1980's, he says, "there were 16 studies (worldwide) involving chromium supplements, and 14 of them showed positive responses to chromium. That's pretty good odds."

The converse, says Anderson, is that many diabetes cases in the United States and other developed countries are probably triggered by too little chromium in the diet. A small but growing number of physicians are becoming aware of chromium's ability to keep blood sugar in check and recommend that their patients consume more.

Chromium supplementation has also improved blood cholesterol and triglyceride levels in study subjects because it takes part in fat metabolism as well as sugar metabolism, he says. And it has increased blood sugar in patients with low levels, or hypoglycemia.

Until the early 1980's, U.S. diets appeared to provide adequate chromium.

That's when researchers found that contamination from stainless steel laboratory equipment, which is about 18 percent chromium, was producing false readings of chromium content. Also, consumption of more and more processed foods and the recent switch to nonmetal cookware combine to reduce the amount of chromium in our diets, says Anderson.

5.3 million people are believed to have type II diabetes but don't know it.

He estimates that 90 percent of the U.S. population gets less than the minimum suggested intake of 50 micrograms (mcg)—that's only 50 millionths of a gram—per day. And one quarter of Americans get only 20 mcg or less in their daily diets.

The National Research Council's estimated safe and adequate intake is 50 to 200 mcg per day.

"A normal diet contains about 15 mcg of chromium per 1,000 calories. Based on that ratio, you'd have to take in more than 3,000 calories a day to get 50 mcg of chromium. But many diets provide only 10 to 15 mcg of chromium per 1,000 calories. At that rate, you're talking about 5,000 calories a day," Anderson says.

During the latest study at the Beltsville Center, 17 volunteers ate meals designed to provide the 15 to 20 mcg of chromium per day consumed by one-quarter of Americans. After 4 weeks of adjusting to the low-chromium diet, the volunteers were given a daily 200-mcg chromium supplement or a look-alike placebo for 5 weeks to see if extra chromium would improve glucose tolerance. Neither the scientists nor the volunteer knew which pill he or she was getting at a particular time until after the study was over.

The eight volunteers who began the study with moderately elevated blood glucose (none were diabetic) had significantly better glucose tolerance while getting the supplement compared to the placebo. After 5 weeks on each capsule, subjects were given a glucose drink and tested 90 minutes afterward; it was found that their blood sugar rose about 40 to 50 percent less with the supplement than it did with the placebo. And levels of insulin and glucagon—another hormone involved in transporting glucose—were also significantly lower.

But the chromium supplements had no effect on the glucose levels in volunteers who began the study with normal glucose values. "That's because chromium functions as a nutrient, not as a therapeutic. If you give more of a nutrient to people who have plenty, nothing beneficial happens," says Anderson.

It did, however, appear to affect how the volunteers felt. "We noticed an energy boost when we were taking the chromium tablets," says Joanne Rector, whose glucose levels were normal to start with. She says some of the volunteers asked if they could get the tablets commercially once the study ended, "because we felt so much better."

The 17 volunteers were divided into two groups based on their circulating glucose levels 90 minutes after drinking the high-glucose cocktail. Those with glucose levels below 100 mg/dL were considered normal; those above, slightly impaired. Anderson says the dividing line is arbitrary because a lot of people with 90-minute glucose levels greater than 100 will not go on to develop diabetes. "The point is, if you can keep them all low, none of them will."

To be sure, a number of other factors can impair glucose tolerance, he says. "If inadequate chromium didn't cause the problem, then chromium supplements aren't going to help." By contrast, a shot of insulin, which is a therapeutic, "will almost always lower blood glucose," he says. And it works immediately, whereas chromium takes time. He notes that before insulin was available, physicians used to prescribe brewer's yeast—which is high in chromium—for diabetic patients.

Elevated blood sugar is not the first indicator that something is going awry with glucose metabolism.

PERRY A RECH

To help researchers determine what effect dietary chromium supplements have on insulin levels, technician Pat Howard (right) draws blood samples from volunteer Joanne Rector. (K-3737-14)

PERRY A RECH

Chemists Richard Anderson and Marilyn Polansky load vials into a high-speed gamma radiation counter that will measure insulin concentrations in blood. (K-3721-13)

Elevated blood insulin is. As the hormone loses efficiency, the pancreas secretes more to process the same sugar load, Anderson explains. Eventually, even the extra insulin isn't enough, and blood glucose levels start to rise. Finally, the pancreas produces less and less insulin, and blood glucose goes out of control.

A person is considered diabetic by National Diabetes Data Group guidelines if he or she has a circulating glucose level above 200 mg/dL at two time points within 2 hours after drinking a glucose cocktail. Anderson has not yet studied the effect of chromium supplements on people with full-fledged diabetes, but others have with mixed results.

They indicate that chromium is effective only when the person is still producing some insulin. It doesn't seem to improve the efficiency of therapeutic insulin, he says. And a 200 mcg-supplement is probably not enough for diabetics.

For example, he cites a 1983 study in South Africa in which researchers gave diabetics a daily 600 mcg-chromium supplement for up to 4 months. Their average fasting glucose levels fell by more than half—from 259 to 119 mg/dL. And 5 of the 13 needed less insulin or oral medication to control blood sugar levels.

Scientists still don't know exactly how chromium works to control blood sugar levels. They do know that biologically active organic chromium binds very tightly to insulin in a test tube and makes the hormone up to 100 times more efficient at getting glucose oxidized to its end point— carbon dioxide, Anderson says.

Although it's very difficult to get enough chromium through the diet, "if you eat a good diet, you may not need as much," he notes. For example, 100 years ago, the per capita use of table sugar was about 4 pounds a year. That has increased to about 115 pounds a year. "First of all, refined sugars are very low in chromium," he says. "And they stimulate chromium losses.

The more sugar is ingested, the more chromium is used and lost.

Anderson has also found that very strenuous exercise can drain the body of stored chromium as can physical trauma from a serious accident.

Chromium studies at the Beltsville Center date back to 1969, when physician Walter Mertz, who had discovered chromium's role as an essential element together with Klaus Schwartz, became the Center director. The element is difficult to scrutinize because of the tiny amounts in foods and the human body. So there have been too few studies on which to base a Recommended Dietary Allowance.

To those who suggest that if 90 percent of the population isn't getting 50 mcg of chromium per day, perhaps the safe and adequate intake is set too high, Anderson says: "We have done studies of people getting normal intakes—25 mcg for females, 33 mcg for males—and they improve with a chromium supplement."—By **Judy McBride,** ARS.

Richard A. Anderson is with USDA-ARS Vitamin and Mineral Laboratory, Beltsville Human Nutrition Research Center, Bldg. 307, BARC-East, Beltsville, MD 20705 (301) 344-2091. ◆

Giving Broccoli Bugs the Brush Off

Integrated program pits beneficials against the pests

President Bush may not like broccoli, but plenty of caterpillars do—so much, in fact, they munch away at thousands of acres of broccoli and related vegetables, causing losses estimated at more than $35 million each year.

Resistance to pesticides by some of these ravenous green worms has rendered many chemical controls ineffective. To remedy the situation, ARS scientists in Yakima, Washington, are putting together an IPM (integrated pest management) program that relies on a smorgasbord of beneficial agents to pare down pest populations.

The pests, which include cabbage loopers, imported cabbage worms, and diamondback moth larvae, attack broccoli, cabbage, cauliflower, and other cole crops. The adults, which are moths and butterflies, don't harm crops—it's only the larvae that damage vegetables.

But carefully timed releases of parasitic wasps, flies, and viruses—all harmless to humans—can stop the destructive creepers in their tracks. The beneficial wasps and flies lay eggs in or on the caterpillars. When these eggs hatch, the hungry larvae feed off the caterpillar host, eventually killing it. The viruses infect the crop-destroying caterpillars, multiplying until they literally consume them.

Entomologist K. Duane Biever, at Yakima's Fruit and Vegetable Insect Research unit, has tested several parasite combinations in field plots during the past 3 years.

By creating a controlled simulation of nature in the vegetable patch, he's finding out which and how many of the helpful parasitic insects and pathogens are needed to keep the pests under control.

Such simulations require huge numbers of insects, which the researchers raise by the millions in humidity- and temperature-controlled rooms.

About a week before the field test begins, research technicians select thousands of pupae from each of the three pest species, placing them in large cardboard boxes. Each box, adorned by windows cut in each side and covered with white gauze, contains about 500 peanut-sized brown pupae—half males, half females.

After the moths wriggle free from their cocoons and mate, Jon R. Kern, a biological technician who works with Biever, plans their release.

In the cool darkness before dawn, Kern carries the boxes to the middle of a broccoli field and opens them. As the sun rises, the moths slowly warm up and flutter to nearby plants, where they lay their eggs.

Timing is critical in every stage of this experiment. Releasing the moths in the early morning avoids

In the cool, still air before sunrise, technician Jon Kern releases cabbage worm butterflies in a broccoli field. (K-3726-1)

DOUG WILSON

DOUG WILSON

heat and high wind gusts, which might cause the moths to fly far from the plot, says Kern.

Once the moths lay their eggs, the researchers watch the tiny eggs closely. When larvae begin hatching from the eggs of all three species, which can take up to 1 week, it's time for the parasite release.

Kern first lets loose a batch of wasp species, since these attack early stages of larvae. Larvae molt as they grow, and the stages between molts are called instars.

Wasps pierce the skin of first-instar larvae, laying 1 to 12 eggs in each caterpillar. The flies, in contrast, lay eggs on top of the fourth- and fifth-instar larvae. Kern releases the flies when he spots third-instar larvae on the plants.

The larval stages of the helpful flies and wasps feed on the host caterpillar without killing it. Following larval development, the parasite eats its way out of the host larva and pupates. Soon after, the host dies.

DOUG WILSON

Diamondback moth larvae *(Plutella xylostella).* (K-3729-5)

The viruses are dusted on the parasites before they're released. The parasites track the viral pathogens onto plants, where they infect the pests—providing a two-pronged attack. The microscopic particles multiply in the pest larvae, consuming the entire caterpillar, "until it looks like a little bag of water," says Kern. The sac bursts, spewing the virus around and infecting any nearby pest larvae that feed on the contaminated foliage.

Diamondback moths—one of three pests used in biocontrol studies—are released into the field by entomologist Duane Biever. (K-3727-1)

Last year's test, which took place on 1-acre field plots, used a combination of six wasp and two fly species. Male-female pairs of each of these 8 species were released at three different rates: low (150 insects per acre); medium (300); and high (600).

All three release rates reduced both pest populations and insect damage at harvest, says Biever. The plots with the two highest release rates produced broccoli with only 5 percent insect damage, compared to 25 percent in a control plot, which received pests but no beneficial insects. Their 1-acre plots yielded about 10,000 heads of broccoli.

According to Biever, the main focus of the research is to show the feasibility of such an integrated biological control approach, which he says can pave the way for innovative pest control practices that are sorely needed.

"New pesticides are harder to come by, and old ones are more tightly restricted, so the type of management system we're designing should be in demand for many crops," says Biever.

Pesticides pose other problems. Not only are they becoming ineffectual, they're also costly—around $300 to $400 per acre.

In Texas and Florida, where most of America's cole crops are grown, thousands of acres of the vegetables were plowed under because pesticides didn't work, according to James R. Coppedge, ARS' national specialist in field crop entomology.

One class of pesticides, known as pyrethroids, "still does a fair job in killing cabbage loopers," says Coppedge. "But farmers used to spray one minimal application only every 2 weeks. Now they use maximum applications every week, and the looper's tolerance is still building."

DOUG WILSON

Cabbage looper moth *(Trichoplusia ni).* (K-3727-9)

Using a biological control approach like Biever's would reduce or eliminate pesticide problems and offer other benefits. For one, parasite releases are self-propagating, because new generations arise from the fly and wasp eggs laid in the pests' larvae. Once parasite populations become established, the helpful flies and wasps could theoretically keep pest populations under control. Also, the beneficial parasites can seek and destroy the pest larvae where they lie—such as the under-

sides of leaves, a place that's hard to reach with pesticide sprayers.

And, unlike pesticides, the parasites work selectively, eliminating only a few undesirable target species. Pesticides kill good and bad bugs alike, further diminishing the possibility of natural control.

The researchers chose broccoli for their model because the crop grows well in the Northwest, and it is targeted by a bevy of bugs that are present every year. Also, because consumers want clean, undamaged broccoli, any new pest control measure must meet fairly stringent criteria. All of these factors "create an excellent challenge for biological control," says Biever.

If the system works well for broccoli, he notes, a similar IPM approach should work even better on crops that don't need to be free of insect damage. Crops such as potatoes, for instance, can tolerate a certain amount of nibbling from pests, since the pests gnaw on the plant's leaves, not the edible tubers consumers buy in markets.

In fact, Biever has already tested similar IPM models to control destructive Colorado potato beetles, using knowledge and strategies gleaned from research on vegetables.

He expects the model will also aid other researchers in developing similar schemes for different crops, even large-acreage crops such as wheat and corn.

"The time is right for developing IPM models that are based largely on biological control," says Biever, "because alternatives for pesticides will be in even greater demand in the 90's."—By **Julie Corliss, ARS.**

K. Duane Biever is at the USDA-ARS Fruit and Vegetable Insect Research Unit, 3706 W. Nob Hill Blvd., Yakima, WA 98902 (509) 575-5877. ◆

Insects Good and Bad—Scientists Must Grow Their Own

DOUG WILSON

Imported cabbage worms, *Artogeia rapae,* transformed into butterflies, mating in a broccoli patch. (K-3727-18)

Thousands of green caterpillars wiggle contentedly in little paper cups inside a warm, quiet room at Yakima's Fruit and Vegetable Insect Research Laboratory. In a nearby building, scores of flies and tiny, clear-winged wasps buzz in small cages.

These insects are central players in an experiment to curb damage to broccoli, cabbage, and other cruciferous vegetables, now underway in the Northwest.

The researchers maintain colonies of 13 different species of flies and wasps that are natural enemies of the crop-destroying caterpillars. Two of the fly species, *Voria ruralis* and *Phryxe vulgaris*, look very much like common house flies. The wasp species resemble ordinary wasps, except they're much smaller and don't have stingers, so they can't harm humans.

In carefully controlled outdoor experiments, scientists set loose these flies and wasps to parasitize the caterpillars in the field.

One of their victims is the green imported cabbage worm, *Artogeia rapae*. Originally from Europe, the worms transform themselves into pale-yellow butterflies.

Lighter green caterpillars living in the lab are cabbage loopers, *Trichoplusia ni*. As adult moths, they will sport brown wings.

There's yet another pale green crawler. Black markings on the adult moth's wings inspired its name—the diamondback moth *(Plutella xylostella).*

To keep these pests alive in the laboratory, scientists prepare special diets made of powdered milk, wheat germ, agar, salt, sugar, and vitamins.

Immature flies and wasps, however, feast on the caterpillars. Researchers place some caterpillars in with adult flies and wasps, who lay eggs in the hapless caterpillars. They'll be eaten by the next generation.

Caterpillars that aren't eaten will become short, fat and dark-colored as they form a cocoon. Researchers collect and store some reserve cocoons in a refrigerator up to 2 weeks for later use in outdoor experiments. Others will develop into moths or butterflies in the laboratory, where they will lay more eggs and continue the cycle.—By **Julie Corliss**, ARS.

To study the effects of atmospheric carbon dioxide on cotton, scientists at the U.S. Water Conservation lab in Phoenix, Arizona, use a circular array of pipes that vent CO_2 into the air—enriching about a tenth of an acre. (K-3751-7)

Greenhouse Effect May Not Be All Bad

Is the climate changing? Yes, but there's no reason for panic, says Sherwood B. Idso, an Agricultural Research Service physicist who has studied climate change since about 1980.

He says that inaccurate assumptions in computer models have resulted in overestimating the damage that global warming will inflict on Earth.

According to Idso, who is with ARS' U.S. Water Conservation Laboratory in Phoenix, Arizona, some climate theorists believe we are already entering a period of drastic alteration in the Earth's climate, triggered by excessive carbon dioxide emissions into the air. They contend that the carbon dioxide will trap the sun's heat in the atmosphere in much the same way that glass in a greenhouse holds heat. In this scenario, as the Earth gets warmer, melting ice from the polar caps will raise ocean levels, perhaps leading to floods in major port cities by the middle of the next century.

> Many crop plants yield more with higher carbon dioxide, temperature

Idso says, "While the increase in carbon dioxide is measurable and global warming may occur sometime in the more distant future, I have come across no evidence that the Earth has already begun to warm. There is cause to be concerned, but I believe changes won't be as rapid or as severe as some sensational news reports indicate. Some changes will even be for the betterment of the Earth's human population—like increased food production."

Average Temperatures Decline

From a review of nearly 1,000 official weather stations across the country, Idso's latest analysis shows U.S. temperatures actually decreasing by a fraction of a degree during the past 70 years.

"Our study, plus a half dozen others, indicates that we have not yet

begun to feel global warming due to the greenhouse effect," says Idso. This work contradicts some scientists' claims that the Earth has already warmed 1°F in the past 100 years.

Idso studied temperatures from weather stations in relatively small towns (6,000 population or less) to eliminate the heat island effect from large urban areas.

When people densely settle in an area, urban heat islands form. "Not only do they bring their own body heat," says Idso, "they burn fires, drive cars, and pave over land that used to reflect more heat and evaporate more water." This, he says, is a localized effect and doesn't indicate what's occurring over the entire country.

In his temperature studies, Idso used data from the U.S. Historical Climatology Network comprising 1,219 weather stations that had long-term records and experienced few instrument and site changes. He worked with Robert C. Balling, Jr., a climatologist at Arizona State University in Tempe.

The average summer temperature change throughout the nation over the past 70 years was up less than 0.01 degree—too small to be significant. The range was from an increase of 4.7°F at Lodi, California, to a decrease of 4°F at Hazelton, Idaho.

During the winter, the extremes were at Baker, Oregon, and Lewisburg, Tennessee—the former experiencing a gain of 6°F and the latter a loss of 7°F. The net wintertime change for the entire nation was a cooling of about 1.5°F.

"Our study found pronounced geographical patterns associated with temperature changes. There has been slight but widespread cooling in the major south-central portion of the United States and slight warming in the northeast and west," says Idso.

"Our climate, like our rapidly changing daily weather, is dynamic rather than static in nature. The climate of the world has continually changed over the eons of time. However, it's only been systematically documented by instrumental observation for less than 150 years," says Norton D. Strommen, weather analyst with USDA's World Agricultural Outlook Board, Washington, D.C.

Earlier documentation comes from analysis of sediment contained in core samples extracted from the ocean floor, from gas molecules entrapped in polar ice, from glaciers, from recorded dates of ice formation on lakes, and from the geological indications left by expansion and contraction of the world's major ice fields with their associated rise and fall in sea level.

JACK DYKINGA

Technician Stephanie Johnson measures photosynthetic rate of leaves on orange trees. (K-3750-7)

Next Century's Air and Today's Crops

"Air concentrations of CO_2 have dramatically increased during the past 20 years mainly because CO_2 is a byproduct of oil, gas, and coal combustion," Idso says.

"Today's air contains about 350 parts per million of CO_2—that's up from levels of 265 in pre-industrial times and 314 as recently as 1958. There's every reason to believe that these levels will continue to increase," says Bruce A. Kimball, an ARS soil scientist who works with Idso in Phoenix.

Such heightened levels of CO_2 are no direct threat to humans. Air contains 78 percent nitrogen, and 21 percent oxygen; the remaining 1 percent is a mix of CO_2, argon, neon, and helium.

"Almost everyone agrees that the amount of carbon dioxide in the atmosphere will double sometime in the mid or late 21st century, but few people agree on how to interpret this—how much warmer the Earth will get and when this will occur," he says.

Last April, representatives from 18 concerned nations gathered in Washington to discuss global warming. Most appeared to agree that the threat is real and needs more attention. The current administration has already earmarked $1 billion for research this fiscal year (FY-91). Plans include planting a billion trees to help absorb CO_2 from the air, says Stephen Rawlins, head of ARS' global change program and member of the agency's National Program Staff at Beltsville, Maryland.

Bruce Kimball is leader of a team that is subjecting crops to environmental conditions like those expected in the next century, including air with a doubled carbon dioxide level.

The largest experiment in ARS is near Maricopa in southcentral Arizona. Called FACE (Free Air Carbon Dioxide Enrichment experiment), it involves 25 scientists studying cotton growing in an environment containing 50 percent more CO_2 than today's air. The research is a cooperative effort with the U.S. Department of Energy and its Brookhaven Laboratory, Upton, New York; Tuskegee University, Tuskegee, Alabama; and the University of Arizona.

The scientists are using a vertical vent pipe array originally developed at the Brookhaven lab to study how pollution affects crops. The array is a ring 70 feet in diameter from which pipes extend upward about 8 feet into the air. Adjustable vents in these pipes allow carbon dioxide to escape into the leaf zone of plants within the ring.

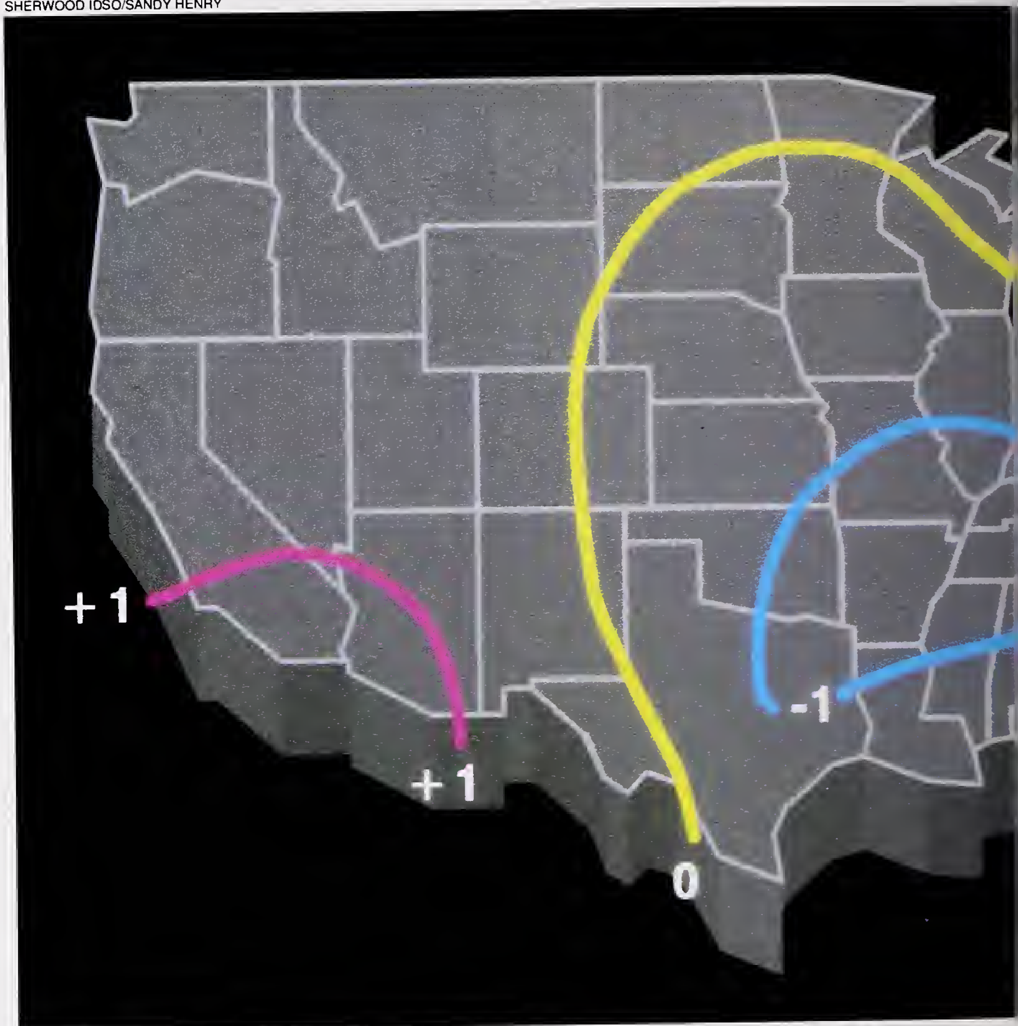
A central computer decides which vents to open based on wind speed and direction and how much CO_2 is needed at each vent to maintain the test environment.

"The crops behave as a natural field crop, and we can collect data representative of future high-CO_2 world conditions," Kimball says. "Because the FACE test area is completely open, we use a lot more carbon dioxide than with plastic-sided open-top chambers that earlier experiments used."

"Cost per year is about $2 million for labor, CO_2, and equipment, which makes the FACE project one of the most expensive plant experiments ever conducted," he says.

However, the plots are relatively large, and there is an economy of scale, as the cost per unit of treated experimental plant material is less than that of other methods. Enough plant material is produced to support the work of the many participating scientists.

SHERWOOD IDSO/SANDY HENRY



Average annual temperature changes in the United States from 1920 to 1984. (K-3686-1)

The open-topped chambers made it easy to regulate and maintain the level of CO_2 around plants inside, but the structures created their own micro-environment. For example, the chamber walls protected plants from winds and migrating insects and heated the air around plants.

FACE is providing more basic scientific data that will help explain how changes will affect all crops.

The studies also indicate that crops in the 21st century will probably produce 30 percent more food if CO_2 content in the Earth's atmosphere doubles and the climate does not change.

All plants, including wheat, rice, and corn—the three major foods for Earth's population—will benefit from extra CO_2, a gas plants need for photosynthesis. Range plants should also produce more feed for livestock, so meat production might increase.

Plant Growth in a Changed Atmosphere

Other researchers cooperating on the project are developing a crop growth simulation model called $COTCO_2$ to predict how increased atmospheric CO_2 and any associated climate change will affect cotton growth and water use in the future.

The Arizona scientists found that crop yields greatly increased when both temperature and CO_2 levels were elevated.

"Using the 6°F-temperature increase that some climate modelers predict will accompany the CO_2 rise, we see worldwide crop yields increasing by 56 percent rather than the 30 percent increase our previous calculations generated," says Idso.

"This shouldn't present problems for agricultural production because the change will be gradual. Plant breeders and genetic engineers will have more than enough time to develop new varieties that thrive in the changed environment.

Idso says, "Climate models suggest rainfall will increase about 10 percent worldwide when CO_2 doubles. This would probably not be felt equally everywhere—perhaps some areas may get even less than now. No one has great confidence in predicting what will happen in any specific region."

Besides, modern farmers are already adept at switching farming practices if it proves more profitable, says Rawlins. For example, U.S. farmers now grow about 65 million acres of soybeans every year, up from the 5 million acres around 1940.

So far, Kimball has reviewed more than 140 studies conducted over a 70-year period; nearly all show that crops will produce more, with cotton leading the list with a projected yield increase of about 60 percent with a CO_2 doubling. Small grains such as wheat and rice might increase 36 percent; corn, 16 percent.

Physicist Sherwood Idso (left) and soil scientist Bruce Kimball assess fruit production on orange trees enriched with CO_2 in an open-topped chamber. (K-3749-1)

JACK DYKINGA

Perhaps the most dramatic indication is that citrus trees appear to grow almost three times faster in elevated CO_2. Idso says that young sour orange trees of the type used for root stock had 2.79 times as much volume of wood after 2 years of exposure to a near doubling of CO_2 in open-topped chambers.

Plants respond in other ways too. "When CO_2 levels are 650 parts per million, or nearly double what today's air contains, plants make more efficient use of water. They use about the same amount to produce more plant material," says Jack R. Mauney, retired ARS plant physiologist and collaborator at the Western Cotton Research Laboratory, also in Phoenix. "They will probably need more fertilizer, although we have found a big response to CO_2 even at low fertility levels."

Problems with insects and mites may change also. "Individuals of the beet armyworm, a leaf feeder, remained in the larval stage longer and the number of adults was reduced. But unfortunately, since it's the larvae that do the eating, damage to cotton was much greater. Growers may have to be more vigilant against this pest in the future," says entomologist David H. Akey, also at the cotton lab.

"Populations of spider mites and whiteflies were about twice as high in plots with extra CO_2. In contrast, individual pink bollworms, which are seed feeders, were no different on cotton in CO_2-enriched field plots," Akey says.—By **Dennis Senft,** ARS.

Bruce A. Kimball and Sherwood B. Idso are at the USDA-ARS U.S. Water Conservation Laboratory, 4331 E. Broadway, Phoenix, AZ. ◆

JACK DYKINGA

Budworms and Bollworms Targeted by a Virus

A virus deadly to the cotton bollworm and the tobacco budworm is sprayed along field edges, borders, and treelines. Pilots and aircraft were furnished by USDA's Animal and Plant Health Inspection Service. (K-3663-15)

Even scientists need to use good public relations to accomplish their goals. The case of spraying a live insect virus over a 100-square-mile area in the Mississippi Delta last spring comes to mind. The research goal: to reduce the populations of two major cotton and tobacco pests, *Helicoverpa zea* (the cotton bollworm) and *Heliothis virescens* (tobacco budworm), by using a natural enemy. The weapon: the *Heliothis* nuclear polyhedrosis virus.

"The virus is not new, but using it to spray weeds near cottonfields is. So we had no way of knowing how the public would react to the first widespread use of an insect virus," says Marion R. Bell, an Agricultural Research Service entomologist in Stoneville, Mississippi.

Bell specializes in microbial control of insects. Treating the entire Delta—an area of about 4.7 million acres—with the virus and without use of chemicals could cost as little as $7 million. That's about 14 percent of the $50 million a year presently incurred by Delta farmers in damages and chemical control of budworms and bollworms. Damages from the tobacco budworm run as high as $1 billion nationwide each year, says Dick Hardee, director of ARS' Southern Insect Management Laboratory at Stoneville.

> The approach is solid, and the word is out that our virus is harmless to every living thing except the target pests.

But large goals are begun with small steps. "Our first task was to convince local farmers, including catfish producers and other people living near the test site, that the virus is safe and won't harm people, animals, plants, or the environment," says Bell.

Five months before the test, an intensive public information campaign was begun by the scientists themselves, the Delta Council (a regional economic development organization), and personnel from Sandoz Crop Protection, Inc., suppliers of the virus.

The researchers went face-to-face with farmers, congressional representatives, extension and university personnel, other scientists, environmental and health officials, and physicians. They told local civic clubs, garden clubs, environmental interest groups, and private interest groups about the virus to be sprayed, its safety, and how it was to be used.

"People needed to know that the virus is very specific," says Bell, "because it works only on certain larvae that have an alkaline midgut.

JACK DYKINGA

Technician Shawn Thomas collects wild geranium heads. Later, she'll assess the aerial spray's coverage, virus activity, and persistence. (K-3664-11)

Once eaten by the larvae, the virus multiplies in the insect until the worm dies. It takes about 10 days for the virus to do its job." The virus isn't even harmful to adult moths of the same species.

A month before the test, each resident in the test area was given an informative brochure. Researchers visited the catfish producers in the test area and got permission to spray the virus around their ponds.

In order to ensure the safety of catfish, the virus was further tested on fish grown at Mississippi State University. No toxic effects were found, nor did the virus produce any off-flavor in the catfish.

Aircraft applied 1,653 pounds of the virus in 25,020 gallons of water. Trucks applied another 145 pounds along main roadways in the area.

Two airplanes were used in the test and loaded to deliver 2 ounces in 2 gallons of water per acre. Earlier tests showed that using this application rate resulted in more than a 90-percent reduction in adult emergence.

The selected site was a 100-square-mile area (64,000 acres) between Leland and Indianola, Mississippi, where during early spring, plenty of insect larvae feed on weeds like wild geranium before emerging as moths. These moths then fly to and lay eggs on fields of cotton and other crops.

Pilots and aircraft furnished by USDA's Animal and Plant Health Inspection Service sprayed only along field edges, borders, fallow fields, and treelines. Twenty-one temporary workers were employed at various times during the test.

JACK DYKINGA

Entomologist Marion R. Bell (foreground) and technician Don Misner prepare an area to be protected from the virus spray. Later, numbers of emerging moths in this area will be compared to those in treated areas. (K-3662-15)

This year's test conditions were less than ideal because of unusually high winds. "Only 12 to 22 percent as much virus was deposited on the weeds compared with earlier studies on small test plots," says Bell.

"But even with less coverage, we found up to 38 percent fewer *H. virescens* and 31 percent fewer *H. zea* emerged in the treated area compared to an untreated area," says entomologist Jane L. Hayes, formerly with ARS.

Next spring, Bell hopes to make one major change in the test. "We'd like to get more of the virus on target plants. To do this, we'll have to do more broadcast spraying over weeds in the test area. We may mix the virus in cottonseed oil instead of water to keep it from evaporating before it hits the target," says Bell.

Helicoverpa zea (formerly classified as *Heliothis zea*) and *Heliothis virescens* attack many other food, fiber, and forage crops in addition to cotton and tobacco. Because both insects rapidly develop resistance to chemicals now used to control them, researchers are hopeful that alternate methods, such as the *Heliothis* virus, will be effective against these pests.

"All in all, this year's results are promising, and we learned what we need to know for 1991," says Hardee. "The approach is solid, and the word is out that our virus is harmless to every living thing except the target pests."—By **Linda Cooke, ARS.**

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REGINA O. HUGHES

Bindweed

Mighty Mite Takes on Bindweed

A small mite has been given the okay for a big job—controlling one of the worst weeds that strangles domestic crops.

It took exhaustive studies, but Agricultural Research Service entomologist Sara S. Rosenthal proved that a mite from Europe, *Aceria malherbae*, attacks only field bindweed and a few closely related weeds.

Field bindweed is a vine—actually an out-of-control morningglory—that can squeeze out crop plants by growing around their stems. With roots that may reach 30 feet into the soil, bindweed steals nutrients that should feed crops. It also serves as a reservoir for crop insects and diseases, says Rosenthal, of ARS' Rangeland Weeds Laboratory in Bozeman, Montana.

The weed is most serious in the West and Midwest where it is difficult and expensive to control with herbicides and cultivation. It continues to spread despite the use of newer herbicides developed for perennial weeds.

Field bindweed is the 15th worst weed in the United States; crops that are particularly hard hit include corn and wheat.

Culver J. Deloach, Jr., and Paul E. Boldt, ARS entomologists at the Grassland Protection Research unit, Temple, Texas, cooperated with Rosenthal in introducing the bindweed-eating mite to the United States.

They released mites in the spring of 1989 in northern Texas and New Jersey. At both sites, the mite overwintered, an indication that it's adapting to its new home. The scientists will continue to measure how well *Aceria malherbae* thrives and controls bindweed.

The mite joins another imported moth that attacks bindweed, *Tyta luctuosa*. This summer marks scientists' third attempt at getting it established; previous releases failed because the areas were too hot or too dry. This summer the moth was released in more favorable climates—southwestern Arkansas and central Missouri.

Rosenthal and fellow entomologists continue their search for other exotic mites and insects. Often it's a combination of hungry bugs that brings weeds under control. Some eat roots; others, like these, feed on stems or leaves. Eventually, when the insects take enough energy from the weed, it dies.

Scientists at the agency's Biological Control of Weeds Laboratory located near Rome, Italy, collect and ship the mites to Boldt and Deloach. The Rome laboratory specializes in locating such European insects. Many of our troublesome weeds were accidentally brought to the United States with the imported crop seed. Unfortunately, their weed-eating enemies usually stayed behind in the old country.—By **Dennis Senft,** ARS.

Sara S. Rosenthal is at the USDA-ARS Rangeland Weeds Laboratory, Culbertson Hall, MSU, Bozeman, MT 59717 (406) 994-4892. Culver J. Deloach, Jr., and Paul E. Boldt, are at the USDA-ARS Grassland Protection Research Unit, 808 East Blackland Road, Temple, TX 76502 (817) 770-6520. ◆

Fungus Found by Accident Protects Lettuce

Lettuce growers may get to keep a little more of the green stuff—the spendable kind—for themselves in the future, thanks to a natural fungus discovered by Agricultural Research Service scientists.

The happy discovery is *Sporidesmium sclerotivorum,* and its favorite snack just happens to be a fellow fungus, *Sclerotinia minor,* that causes severe losses in lettuce, peanuts, and other crops. Scientists say spraying *Sporidesmium* on fields infested with *S. minor* could cut crop losses to that fungus by 50 percent or more.

Lettuce producers aren't likely to shed many tears over the demise of *S. minor,* since it's the culprit behind lettuce drop, which reduces the plants to a wilted brown heap.

"Once this fungus is in a field, you have it every year, although the severity of the problem will depend on factors such as temperature and moisture," says ARS plant pathologist Peter B. Adams.

The bad fungus' spores are hard little balls 1 to 2 millimeters in diameter, which normally helps it persist in the field. But the tough rinds on these balls can't hold up to *Sporidesmium sclerotivorum,* according to Adams, who accidentally discovered the good fungus at Beltsville, Maryland, in 1976.

"I had placed *S. minor* in some soil from fields at Beltsville for a greenhouse experiment," Adams recalls.

"When I came back a month or two later, I couldn't find it in the soil. So I took a closer look and found the soil was infested with this mycoparasite," he says. The mycoparasite was later identified as a new species of the genus *Sporidesmium.*

The method of naturally controlling *S. minor* with *Sporidesmium* was patented by ARS in 1981.

A cooperative agreement is pending for commercial development of the biocontrol agent. Farmers have other weapons against *S. minor,* in the form of both fumigants and fungicides. But fungicide treatments can run $200 per

acre, with fumigation as high as $1,000 per acre, says Adams.

"By comparison, you could treat your fields with *Sporidesmium* for about $10 per acre," he notes. "In tests here at Beltsville using different rates, we got 50 percent control of the disease with only two-tenths of a pound.

"Chemicals may not give you much more control than that; if you can consistently get 80 percent control with chemicals, you're doing well. In addition, *Sporidesmium* isn't going to pollute the groundwater, and it won't leave chemical residues on the crop or in soil."

While *Sporidesmium* can be slow to take action, each application offers relatively long-term protection. In field tests at Beltsville, the fungus has survived for up to 30 months.

"I think *Sporidesmium* is in nearly every agricultural field, but it sometimes occurs in such low levels that we can't find it," Adams says. "We didn't realize it, but it's been out there giving us natural biocontrol all these years. Now we're enhancing that."—By **Sandy Miller Hays**, ARS.

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PERRY A. RECH

Plant pathologist Peter Adams probes a culture of the fungus *Sclerotinia minor*, that is known to cause severe damage to lettuce crops. (K-3782-2)

PERRY A. RECH

St. Croix hair sheep have a high resistance to certain internal parasites such as barber-pole stomach worms. (K-3720-8)

St. Croix Sheep Resist Worms

At first glance they look like goats grazing with the sheep, but ARS scientists know better. They are hair sheep originally from the Island of St. Croix.

"They may look a bit odd, but hair sheep may be the key to controlling nematode parasites, worms that cost U.S. sheep farmers about $45 million annually," says zoologist H. Ray Gamble.

When put on pasture alongside Dorset sheep, a breed common to the eastern United States, hair sheep proved highly resistant to worms in a short period of time. The Dorsets had to be medicated to prevent the worms from killing them.

"The hair sheep had 99.9 percent fewer worms in their fourth, or true, stomach and passed 99.5 percent fewer parasite eggs in their feces when compared with untreated Dorsets," says Gamble.

"We don't know for sure why this happens, but we discovered that the hair sheep had more immune cells called globule leucocytes in their true stomachs than did the Dorsets. These cells appear to prevent the worms from invading the stomach lining, a necessary step in the cycle of infection," says Gamble. "Most scientists would recommend breeding this immunity into the more susceptible sheep," says veterinarian Anne Zajac of the Virginia/Maryland Regional College of Veterinary Medicine, Blacksburg, Virginia. "But this has proven of limited value so far because much of the resistance to the parasitic worms is lost in the offspring."

"To get immunity into other breeds may involve a combination of breeding and new vaccines," Zajac says. "We have to find out more about how the immune cells actually repel, kill, or inhibit the worms.

The immunity question becomes even more important considering the fact that cattle worms, with their $300 million annual price tag to farmers, cause damage similar to that of sheep worms. A control for sheep worms could very well lead to one for cattle, Zajac says.

All U.S. flocks of hair sheep, including those at the Beltsville Agricultural Research Center, Beltsville, Maryland, are descendants of two sheep imported into the United States in 1975. They were brought here because they produce leaner meat on poorer forage. Like most livestock bred in warmer climates, they have fewer problems with parasites than the traditional wool-bearing sheep raised here.

"The fact that these sheep are highly inbred may give us an advantage in our research. It means that they are genetically similar and our research results should be more uniform than those from sheep that are markedly different in their genetic composition," says Gamble.—**By Vince Mazzola,** ARS.

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